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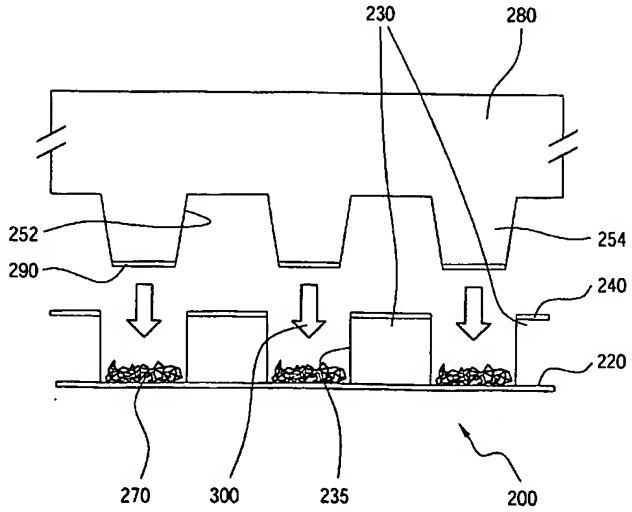
(54) Title: FIELD EMISSION DISPLAY AND METHOD OF MANUFACTURING THE SAME



(57) Abstract: A field emission device (200) comprises a substrate on which an emitter material (270), such as printed CNT paste, is provided. During manufacturing, the emitter material (270) is activated by bringing a patterned mould or stamp (280) comprising an adhesive material into adhesive contact with the emitter material (270). The adhesive contact is such that it provides sufficient adhesive force when the stamp (280) is separated from the material (270), or vice versa, so that at least a portion off the emitter material is removed or rearranged to form a new emission surface on the emitter layer (270). The pattern of the mould or stamp (280) should match that of the emitter structure of the field emission device (200). Preferably, the adhesive material is provided as an adhesive layer on contact surfaces of protrusions of the stamp (280), which is suitable for activating emitter material inside the gate holes (235) of a triode structure for a field emission display.

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Field Emission Display and method of manufacturing the same

This invention relates to a method of manufacturing a field emission device. The invention further relates to a field emission device and to a display device comprising such a field emission device.

A field emission device may be used, for example, as an electron source for a flat-panel type display, the so-called Field Emission Display (FED). The FED is a vacuum electronic device, sharing many common features with the well-known Cathode Ray Tube (CRT), such as low manufacturing costs, good contrast and viewing angle, and no required back-lighting.

Field emission is a quantum-mechanical phenomenon in which electrons tunnel through a potential barrier at an outer surface of a suitable emitter material, as a result of an applied electric field. The presence of the electric field makes the width of the potential barrier at the above-mentioned outer surface finite, so that this potential barrier is permeable to electrons. Thus, electrons may be emitted from the field emitter material.

A field emission device commonly employs a gate structure (also called a triode structure). The gate structure includes the field emitter material and two electrodes, namely a cathode electrode and a gate electrode. Between these electrodes, in operation, an electric field is created which allows emission of electrons from the field emitter material, which is usually located on the cathode electrode.

In a field emission display, the field emission device employs two sets of electrodes, more particularly, a set of cathode electrodes and a set of gate electrodes. The sets of electrodes generally define a passive matrix structure of rows and columns. Thereby, the electric field, and thus the electron emission current, may be modulated independently for each pixel on the display screen of the field emission display.

In order to obtain a sufficiently high strength of electric field over the field emitter material, the cathode and gate electrodes should generally be relatively close to each other and, in order to achieve this, a dielectric layer is provided between the sets of electrodes. Such a dielectric layer is then usually patterned.

For example, in a normal configuration of the gate structure, a cathode electrode is provided on a substrate, and a dielectric layer and a gate electrode are arranged

over the cathode electrode. Gate holes are provided extending through the dielectric layer and the gate electrode. The field emitter material is provided on the cathode electrode, at the bottom of the gate holes. Thus, the dielectric layer (and the gate electrode) have to be provided with these gate holes, through which emitted electrons pass. The gate holes are preferably relatively small, having for example a diameter in the order of several micrometers, in order to achieve good electron emission from the field emitter.

There is a continuing need in technology to provide improved field emission properties of field emission displays, so as to increase emission current density at relatively low field and provide uniform emission.

International Patent Application WO 01/99146 describes an activation process for improving the field emission of electron field emitter in which an adhesive material is brought into contact with the electron field emitter such that when the material is removed therefrom, a portion of the electron field emitter adheres to the adhesive material so as to form a new surface of the electron field emitter.

In the process described in International Patent Application WO 01/99146, adhesive tape is used to activate an area of emitter film. The approach of using adhesive tape to activate emitter film has been found to render significant improvement of electron emission in terms of very high emission current density at low field and very uniform emission.

However, this process is only applicable to relatively large and flat emitter film areas. The proposed process involves the use of tape to activate emitter film on a cathode with gate structure with gate dimensions of 600 microns. It is worth noting that 600 micron gate holes are larger than the pixel size desirable for a display device. Moreover, such gate holes have unsatisfactory current-driving voltage characteristics to be practically used in FEDs. Gate structures with realistic gate dimensions for field emission displays and the like, for example, have a diameter of the order of 10 microns.

However, there is a problem that the tape approach described in WO 01/99146 is not feasible for gate structures with such small gate hole dimensions. The activation of the field emitter material is the insufficient. Furthermore, the tape used will not only adhere on the emitter film, but also on the other surfaces of the gate structure, which should be avoided because of the attendant risk of damaging the gate (electrode) structure.

An alternative process for use in activating emitter film involves the use of laser treatment. This would alleviate at least some of the problems outlined above, but laser treatment is relatively expensive, and therefore significantly increases the manufacturing cost of a FED. Furthermore, the same significant improvement in field emission cannot be achieved using laser treatment, compared with that observed using the process described above using adhesive tape.

It is an object of the invention to provide a manufacturing method for a field emission device, which is able to generate a relatively high emission current and suitable for use in a field emission display.

This object is achieved by the method according to the independent Claim 1. Thus, there is provided a method of manufacturing a field emission device, including the steps of

- providing a layer of emitter material on a substrate,
- contacting an adhesive material with said emitter material, and separating said adhesive material from said emitter material,
- said adhesive material being arranged to form an adhesive contact with said electron field emitter and providing sufficient adhesive force when said adhesive material is separated from said electron field emitter, so that at least part of said electron field emitter is removed or rearranged, thereby forming a new surface of said electron field emitter,

the method being characterised by the further step of providing a patterned mould or stamp comprising said adhesive material, and said step of contacting an adhesive material to said emitter material comprises engaging said patterned mould or stamp with said emitter material.

The method of the present invention enables the activation of emitter film patterned on complex and patterned emitter structures, such as a triode structure in a field emission display. The method relies on the use of a patterned mould or stamp made from an adhesive material, or provided with an adhesive material. The pattern of the mould or stamp should match that of the emitter structure. In this case, the adhesive material substantially only contacts the field emitter material, and not the other parts of the field emission device such as the electrodes. Thus, damaging of the field emission device by the adhesive material is prevented, and electron emission from the device is improved.

It is noted that in the applicant's unpublished European patent application PHNL021230EPP, there is proposed a method of manufacturing a field emission device, in which a layer of liquid material is provided on a substrate. In this method, also a patterned stamp or mould is used, which in this case is engaged with the layer of liquid material, so as to emboss the layer, following which the layer of liquid is cured to form a solidified, patterned dielectric layer. It will be appreciated that it is highly beneficial, if not essential, to ensure that the patterned stamp used in this type of arrangement does not adhere in any way to the liquid material or any other part of the device. Accordingly, it may be specially treated, if required, to prevent this.

In the method according to the present invention, the mould is preferably provided with a patterned adhesive contact area, which may be defined by one or more alternate protrusions and recesses. More preferably, at least the contact surfaces of the protrusions comprises said adheisve material. That is, the contact surfaces are formed of said adhesive material, by surface modification or otherwise, or the contact surfaces are coated with an adhesive layer.

The size of the protrusions can be chosen to match the dimensions of the gate holes in the triode structure of a field emission device. Thus, the protrusions have a size in the order of 10 microns. This allows activation of the field emitter material in relatively small gate holes, such as the gate holes used in a field emission device for a field emission display.

In a preferred embodiment, the portion(s) of the mould or stamp arranged to contact said emitter material are tapered away from the contact surface, such that substantially only the central area of the emitter film in the gate holes is activated, which prevents shorts from occurring. In one embodiment, one or more of the above-mentioned protrusions are substantially frusto-conical. Alternatively, said portion(s) may have a smaller dimension than the gate holes, which achieves the same effect.

The emitter material may be any suitable material, such as carbon nanotube (CNT) material, such as CNT containing paste, which may be applied to the substrate of the device by a printing process or the like. Such a paste may consist consist of multi-walled or single-walled CNT's or a mixture thereof, preferably being 1-10% of the paste. The remaining paste fraction may consist of a binder, such as theyl cellulose or nitro cellulose, preferably to which particles or frit glass particles, or a mixture thereof, are added.

Also in accordance with the present invention, there is provided a field emission display comprising a display screen and a field emission device for generating electrons,

said field emission device including a field emitter material, a first and second electrode for applying an electric field over said field emitter material, and being manufactured by a method according to one of the embodiments set out in the above.

The field emission device preferably includes a patterned dielectric layer between the first and second electrode, the patterned dielectric layer being provided with gate holes in which the field emitter material is provided. Such a field emission device is well suited for use in a field emission display and has favourable current-driving voltage characteristics. By virtue of the method according to the invention, the field emitter material inside the gate holes may be activated during manufacturing, so that it can generate a relatively high electron current.

These and other aspects of the present invention will be apparent from, and elucidated with reference to, the embodiment described hereinafter.

An embodiment of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic cross-sectional diagram of a field emission device having a normal gate structure; and

Figure 2 is a schematic cross-sectional diagram illustrating apparatus suitable for performing the process according to an exemplary embodiment of the present invention.

An embodiment of a field emission device 100 is illustrated in Figure 1 of the drawings. The illustrated field emission device comprises a substrate 110, a first electrode (cathode electrode) 120, a dielectric layer 130, and a second electrode (gate electrode) 140 formed on the dielectric layer 130. The dielectric layer 130 is a patterned dielectric layer comprising a number of gate holes 135, and is located between the first and second electrodes 120, 140, and is for example made as set out in the above-mentioned unpublished European patent application PHNL021230EPP.

An emitter material (indicated by reference sign 170 in Figure 1) is preferably provided inside the gate holes 135, directly over the substrate 110 and the cathode electrode 120, by means of any suitable technique, such as spin-coating, dip-coating or printing. The gate electrode 140 has a pattern of apertures 145 for passing emitted electrons, which apertures 145 are aligned with the gate holes 135.

The dimensions of the gate holes 135 in the dielectric layer 130 are for, example, between 1 and 10 micrometers. By patterning the dielectric layer using a mould or stamp, gate hole dimensions in the sub-micron region, such as 200 or 500 nanometers can also be achieved. Such dimensions may be particularly advantageous when certain types of emitter material are used, for example, carbon nanotubes (CNT's). With carbon nanotubes in particular, it is desirable to have gate holes that are as small as possible, as this allows for more efficient emission of electrons. This requirement originates from the fact that only carbon nanotubes adjacent to the rim of the gate hole contribute to the electron emission. Therefore, with decreasing gate hole size, the number of emitting particles increases, per cathode area.

Referring to Figure 2 of the drawings, the field emission device 200 again comprises a cathode electrode 220 and a dielectric layer 230 on which is provided a gate electrode 240. In the gate holes 235 between the protruding portions of the dielectric layer 230, an emitter material 270, such as printed CNT paste, is provided.

An exemplary embodiment of the method according to the present invention, relies on contacting a patterned mould or stamp 280 with the CNT paste 270. The stamp 280 is made, for example of an elastomeric material, and provided with a layer 290 of adhesive material, such as glue. In the contacting step of the method, the mould 280 is moved downwards (in the direction of the arrows 300) and thereby brought into adhesive contact with the CNT paste 270.

The surface 285 of the stamp 280 which is brought into contact with the emitter material 270 comprises a pattern of recesses 252 and protrusions 254 which matches the patterned dielectric layer of the field emission device, in particular the gate holes 235 in the layer.

In a preferred embodiment, the protrusions 254 of the stamp 280 are frusto-conical in shape, in that they taper toward the contact surface 285. The advantage of using such a tapered mould is that only the central area of the emitter film 270 in the gates is activated, thereby helping to prevent shorts.

Thus, the adhesive layer 290 is brought into contact with the emitter layer 270, and the adhesive contact therebetween provides sufficient adhesive force when the stamp 280 is separated from the material 270, or vice versa, so that at least a portion of the emitter material is removed or rearranged to form a new surface on the emitter layer 270. Thus, when the stamp 280 is separated from the emitter layer 270, the emitter layer 270 is "activated" by partial removal or rearrangement of the upper layer thereof.

Alternatively, the stamp 280 may be at least partially made of an adhesive material, as opposed to be being provided with a layer of such material.

Thus, in summary, the present invention proposes the use of a mould or stamp whose contact with an emitter material is adhesive, such that pressing the adhesive mould on an emitter film and withdrawing it activates and improves the electron emission from the area that was contacted. This approach enables the relatively low-cost and effective activation of emitter film patterned on complex and gated electrode structures. Moreover, by using a tapered mould, only the central area of emitter film in the gates is activated, thereby preventing shorts.

An embodiment of the present invention has been described above by way of example only and it will be apparent to a person skilled in the art that modifications and variations can be made to the described embodiment without departing from the scope of the invention as defined in the appended claims. It will be further understood that the term "comprising" herein does not exclude other elements or steps, "a" or "an" does not exclude a plurality, and a single processor or other unit may fulfil the functions of several means recited in the claims.

CLAIMS:

1. A method of manufacturing a field emission device (200), including the steps of

- providing a layer of emitter material (270) on a substrate,
- contacting an adhesive material (290) with said emitter material (270), and separating said adhesive material (290) from said emitter material (270),
- said adhesive material (290) being arranged to form an adhesive contact with said emitter material (270) and providing sufficient adhesive force when said adhesive material (290) is separated from said emitter material (270), so that at least part of said emitter material (270) is removed or rearranged, thereby forming a new emission surface, the method being characterised by the further step of providing a patterned mould or stamp (280) comprising said adhesive material (290), and said step of contacting an adhesive material to said emitter material comprises engaging said patterned mould or stamp (280) with said emitter material (270).

2. A method according to claim 1, wherein said patterned mould or stamp is provided with a patterned adhesive contact area.

3. A method according to claim 2, wherein said patterned adhesive contact area is defined by one or more alternate protrusions (254) and recesses (252), at least the contact surfaces of the protrusions (254) comprising said adhesive material (290).

4. A method according to claim 1, wherein the portion(s) of the mould or stamp arranged to contact said emitter material are tapered away from the contact surface.

5. A method according to claim 4, wherein said portion(s) are substantially frusto-conical.

6. A method according to claim 1, wherein said emitter material comprises carbon nanotube (CNT) material.

7. A field emission display comprising a display screen and a field emission device (200) for generating electrons,
said field emission device including a field emitter material (270), a first electrode (220) and second electrode (240) for applying an electric field over said field emitter material, and said field emission device being manufactured by a method according to any one of the preceding claims.

8. A field emission display according to claim 7, wherein the field emission device includes a patterned dielectric layer (230) between the first electrode (220) and second electrode (240), the patterned dielectric layer (230) being provided with gate holes (235) in which the field emitter material (270) is provided.

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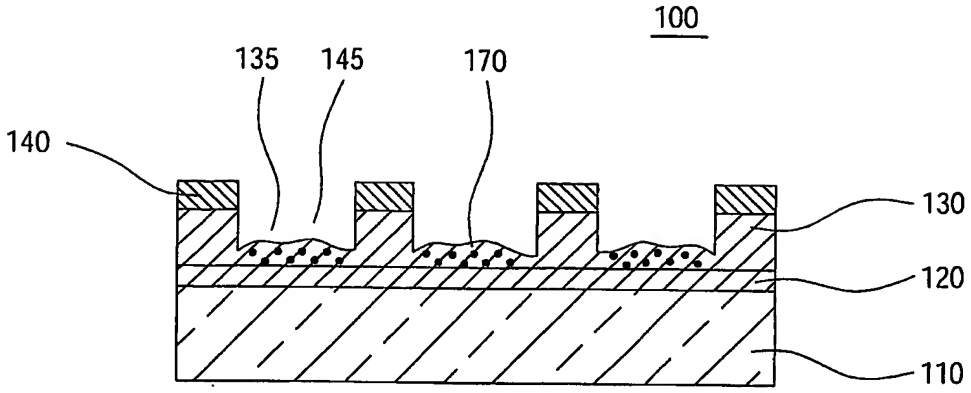
100
135
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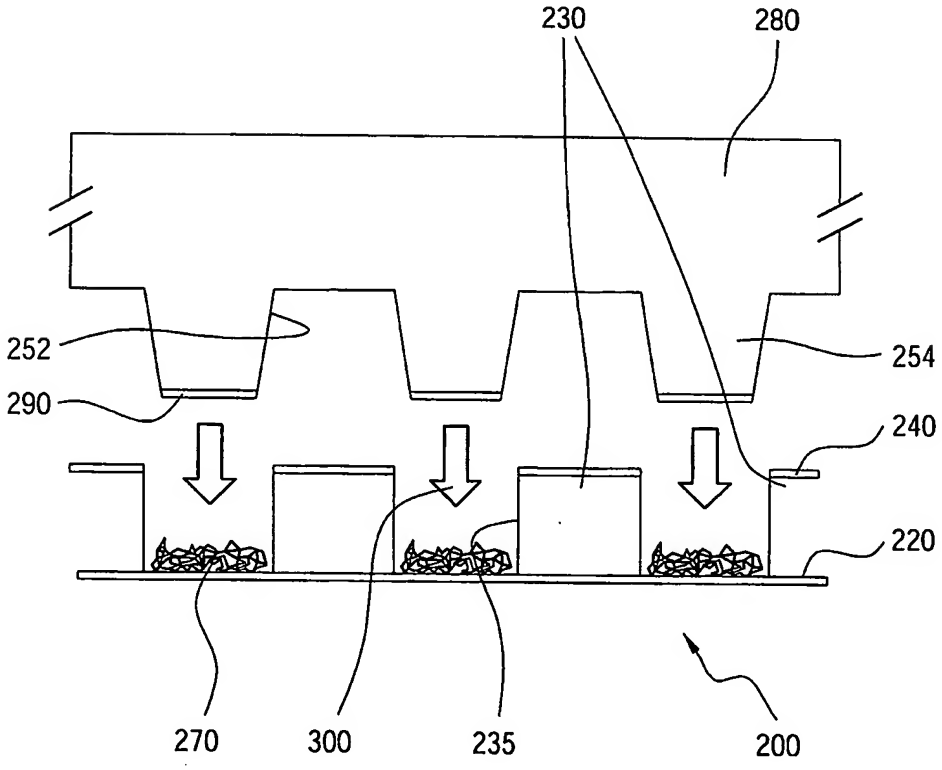
FIG. 1


230
280
252
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235
200

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J9/02 H01J1/304 H01J29/48

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/092207 A1 (MAO DONGSHENG ET AL) 15 May 2003 (2003-05-15) paragraph '0046!; figure 8 paragraph '0047!; figure 7	1-3,6-8
A	US 2002/104603 A1 (CHANG YU-YANG ET AL) 8 August 2002 (2002-08-08) abstract paragraph '0010!	1,6-8
A	US 2002/197928 A1 (LEE SANG-JO ET AL) 26 December 2002 (2002-12-26) paragraphs '0030! - '0050!; figures 1,2	1,6-8
A	WO 01/99146 A (LAVIN JOHN GERARD ; ROACH DAVID HERBERT (US); DU PONT (US); BOUCHARD R) 27 December 2001 (2001-12-27) cited in the application abstract; examples 1,16	1,6-8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB2004/050648

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